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(71) Applicant: **SYCAMORE NETWORKS, INC.** [US/US]; 150 Apollo Drive, Chelmsford, MA 01824-0986 (US).

(72) Inventors: **SWANSON, Eric, A.**; 13R Oakwood Road, Acton, MA 01721 (US). **LI, Ruo, Ding**; 42 Nylander Way, Acton, MA 01720 (US).

(74) Agents: **LEBOVICI, Victor, B.** et al.; Weingarten, Schurgin, Gagnebin & Hayes, LLP, Ten Post Office Square, Boston, MA 02109 (US).

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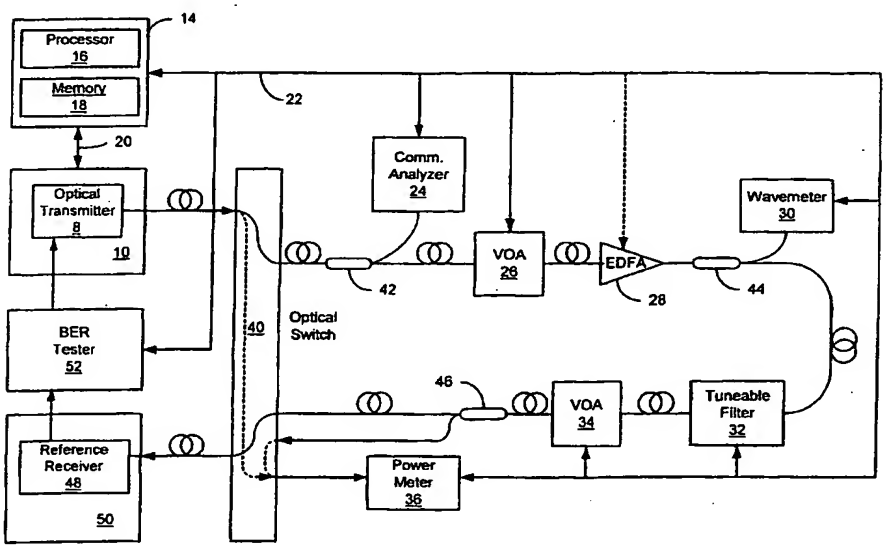
(54) Title: IN CIRCUIT BIASING AND TESTING OF A LASER IN A WDM TRANSCEIVER BOARD



(57) Abstract: A method and apparatus for in-circuit biasing of a modulated laser (8) and a bit error rate testing of an optical transmitter and/or optical receiver (9) under the control of a test controller. The test controller is communicably coupled to an interface of a module (10) under test, as well as to external test equipment. The test controller modifies operational parameters of the modulated laser (8), in order to obtain a desired output power and to obtain a predetermined extinction ratio. The operational parameters of the laser (8) include a laser bias current, and electro-absorption modulator offset bias current and a modulation depth.

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IN CIRCUIT BIASING AND TESTING OF A LASER IN A WDM TRANSCIENVER BOARD

CROSS REFERENCE TO RELATED APPLICATIONS

N/A

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

N/A

BACKGROUND OF THE INVENTION

The invention relates generally to the manufacture and test of optical transceivers including a modulated laser, and more specifically to an automated system and method for biasing and driving a modulated laser, such as an electro-absorptive modulated laser in an optical transceiver, in order to achieve desired operational characteristics, and for bit error rate screening of optical transmitters and receivers.

Communication devices using optical transmission technologies have been increasingly employed in recent years to satisfy the demand for large capacity digital transmission in communication networks, such as public telecommunications networks. In its basic form, an optical communication system includes a modulated laser, an optical fiber link and an optical receiver. The laser receives as an input an electrical signal in the form of a high speed serial bit stream which may include both encoded clock and data information. In response to the

received serial bit stream, the laser output intensity is modulated to generate a modulated light signal which is propagated onto the optical fiber link. The light then passes through the fiber to an optical receiver which transforms the received modulated light signal into an electrical serial bit stream. The electrical signal is then amplified, conditioned, and fed to another circuit which performs clock and data recovery.

One challenge faced by manufacturers of optical communication equipment results from the fact that operational characteristics of individual lasers vary to such an extent that each laser and associated modulator must be biased individually to achieve desired power output and modulation characteristics. Existing approaches to this problem have included the manual entry of values which control the operational characteristics of the modulated laser into a non-volatile memory, such as a programmable read only memory (PROM). Such manually entered values are typically based on values provided in data sheets for each individual laser obtained from the manufacturer of the respective laser. This type of a manual process, however, is time consuming and error-prone, and can result in unacceptably high rates of mis-entry, causing operational problems. Additionally, the laser data sheet values used to determine control values for the laser modulators are not based on operational characteristics of the specific laser in the device in which it will be used. Accordingly, control values, such as a laser power bias current control value and EA modulator bias control values, may not be optimally established in existing systems where a laser's in-circuit operational characteristics differ significantly

from the characteristics specified by the manufacturer of the laser. For this reason, existing approaches, whether manual or automated, may not optimally adjust the parameters of the laser and/or receiver to the surrounding circuit.

Another problem in the manufacturing and testing of optical communication equipment relates to the testing of the optical transmitter and receiver functions to determine whether an optical transceiver meets predetermined bit error rate criteria. Where a device is required to operate with a bit error rate (BER) below some specified minimum, testing is desirable to ensure that the desired BER will be met when the transceiver is deployed in a telecommunications network. For example, an optical transceiver board may be tested to determine whether both the transmitter and receiver functions introduce errors at a rate below a threshold bit error rate. In the case where the threshold error rate is extremely low with regard to the transmission rate of the device, such testing may require weeks for each device. Such delays are highly undesirable in a manufacturing process. For example, the testing of a transceiver for a device supporting SONET OC-48 to determine whether it would meet a BER specification of less than 10^{-15} bits per second would require several weeks of continuous test transmissions to get a reliable estimate of the BER. Such long testing periods are costly and delay the shipments of product by the optical transceiver manufacturer. Furthermore, transceivers are often intended for use over long distance, optically amplified links. In such links, as the transmitted optical signal passes through numerous amplifiers, amplifier noise

(Amplified Spontaneous Emission or ASE) accumulates. Accordingly, a performance metric for such amplified, long distance links may be thought of as the ability to maintain a maximum BER as a function of the optical signal-to-noise-ratio (OSNR) at the receiver. It would be greatly beneficial to have an automated system for characterizing transceivers during the manufacturing process as a function of OSNR that does not require multiple amplifiers, due to the costs and maintenance constraints associated with their use.

For these reasons it would be desirable to have an efficient and reliable automated method and apparatus for biasing a modulated laser used in an optical transceiver. The system should reduce the risk of errors occurring during manual entry of control values, and provide a more accurate determination of control values reflecting the actual circuit in which the modulated laser will operate. Additionally, the testing system should permit bit error rate testing down to very low levels using tests that do not involve prolonged test times.

BRIEF SUMMARY OF THE INVENTION

In accordance with principles of the invention, a system for biasing and testing an optical transceiver is disclosed. In a first aspect of the disclosed system, biasing of a modulated laser is performed under the control of a test control system. The test control system may include a computer or test controller, and the steps employed in the determination of the desired bias values are performed in response to a software program executing on the test controller. The test controller is

communicably coupled to the module under test, for example, through a digital interface, such as a serial RS-232 communications link. The test controller may further be communicably connected to an optical power level monitor and other testing devices through a communication bus, such as the General Purpose Interface Bus (GPIB). Through the digital interface to the module under test, or by way of the other testing devices coupled to the test controller through the communication bus, the test controller can modify operational bias parameters of the modulated laser, in order to provide a desired extinction ratio at a desired power output level. The operational parameters may include, for example, the laser power bias current, an electro-absorption (EA) modulator bias offset voltage and an electro-absorption (EA) laser modulation depth. During operation of the disclosed system, the test controller configures the test system, establishes the laser bias current necessary to achieve a desired laser on state output power, determines a desired EA modulator bias current necessary to achieve a desired off state laser power and adjusts a modulation depth control value to achieve the desired extinction ratio.

In another aspect of the disclosed system, the test controller determines whether the optical transmitter and the optical receiver within the transceiver each exhibit an acceptable bit error rate (BER), as a function of either received optical power or received OSNR. To perform the bit error rate testing, the test controller uses a variable optical attenuator, in combination with an erbium doped optical fiber amplifier (EDFA) to control an optical signal to noise ratio (OSNR) in a signal

terminating at either a reference receiver or the receiver of the optical transceiver in the module under test. A bit error rate tester is coupled to a pre-qualified transceiver module which includes a reference transmitter and the reference receiver. The reference receiver and transmitter are employed in conjunction with the transmitter and receiver of the module under test respectively to measure a number of bit error rates corresponding to controlled optical signal to noise ratios. More specifically, the generated optical signal to noise ratios are gradually increased, resulting in lower measured bit error rates. The disclosed system samples the bit error rates for a number of relatively low signal to noise ratios, and projects an optical signal to noise ratio that would be required to obtain a predetermined, relatively low bit error rate. In this manner, the disclosed system avoids the need to actually perform prolonged bit error rate measurements to verify very low bit error rates. If the projected optical signal to noise ratio for the low bit error rate is above a predetermined maximum optical signal to noise ratio, then an indication is provided that the optical transmitter or receiver being tested within the module under test has failed the test. In an alternative embodiment, the transmitted Q over the simulated amplifier link created using the generated optical signal to noise ratio can be measured as an indicator or metric of the transmitted BER quality.

Thus there is provided an efficient and reliable automated method and apparatus for biasing and testing an optical transceiver. The disclosed system reduces the risk of errors occurring during manual entry of laser

bias and modulator control values and provides a more accurate determination of control values desired in the actual module in which the modulated laser well be employed. Additionally, the disclosed system allows bit error rate qualification down to very low bit error rates using tests that greatly reduce the actual test times required for each device.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The invention will be more fully understood by reference to the following detailed description of the invention in conjunction with the drawings, of which:

Fig. 1 is a block diagram illustrating a test system for establishing bias conditions for a modulated laser and testing optical transmitters and receivers in a module under test;

Fig. 2 shows an illustrative optical transceiver board corresponding to the module under test in the test system depicted in Fig. 1;

Fig. 3 is a graph showing laser optical output power as a function of electro-absorption modulator offset bias voltage;

Figs. 4a-4b illustrate steps that may be employed to establish control values for a modulated laser in an optical communication device;

Fig. 5 illustrates steps that may be performed to ascertain a projected optical signal to noise ratio for a relatively low bit error rate of an optical transmitter or receiver in an optical transceiver;

Fig. 6 is a graph illustrating bit error rates of a device under test as a function of optical signal to noise ratios; and

Fig. 7 shows the illustrative testing environment of Fig. 1 configured to test the bit error rate of an optical receiver in an optical communication device.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 illustrates a test system for establishing desired bias conditions for an optical transmitter 8 of an optical transceiver board 10. While for purposes of illustration, the module under test in Fig. 1 is shown as an optical transceiver, the disclosed system could alternatively be used to test transmitter or receiver modules. The module under test, such as the optical transceiver board 10 shown in Fig. 1, may be employed within an optical communication device (not shown) such as an optical repeater or an optical network switch.

Further in the illustrative embodiment of Fig. 1, a test controller 14 is shown including a processor 16 and a memory 18. The test controller 14 is connected to the optical transceiver board 10 through an interface 20, which may consist of a serial communications interface such as an RS-232 interface, or other suitable serial or parallel communications interface. The test controller 14 is further connected to various test equipment and optical devices over a communications bus 22, such as the General Purpose Interface Bus (GPIB) or any other suitable communications bus. The test equipment and optical devices connected to the communications bus 22 include a communications analyzer 24, a first variable optical attenuator 26, an optical wavemeter 30, a tunable optical filter 32, a second variable optical attenuator 34, and an optical power meter 36.

In the configuration of Fig. 1, the signal output from optical transmitter 8 is optically connected, for example by an optical fiber, to an optical switch 40, and then to an optical signal splitter 42. The optical switch 40, however, is optional, and the connections shown in Fig. 1 can alternatively be permanent, or can be manually configured. The signal splitter 42 passes a first portion of the received optical signal to the communications analyzer 24 and a second portion of the received optical signal to the first variable optical attenuator 26. As an optimization, an optical isolator may be employed between the transmitter 8 and the switch 40, or elsewhere in the optical chain to minimize the effects of optical multipath. The first variable optical attenuator 26 passes the received optical signal to an optical amplifier 28, such as an erbium doped fiber amplifier (EDFA), which operates in combination with the first variable optical attenuator to produce a desired optical signal to noise ratio. The optical amplifier 28 may optionally be controlled via the communications bus 22. The output of the optical amplifier 28 is optically coupled to a second optical signal splitter 44. The second optical signal splitter 44 passes a first portion of the received optical signal to a wavemeter 30 and a second portion of the received optical signal to the tuneable optical filter 32. The output of the tuneable optical filter 32 is coupled to the input of the second variable optical attenuator 34 via an optical fiber. The output of the second variable optical attenuator 34 is coupled to a third optical splitter 46. A first portion of the optical signal received at the third optical splitter 46 is coupled to an optical power meter 36, for

example, via the appropriately configured optical switch 40, or by directly connecting a portion of the output of the third optical splitter to the optical power meter 36. A second portion of the received optical signal is coupled from the output of the third optical splitter 46 to the reference receiver 48 within the pre-qualified transceiver 50 via the optical switch 40. An advantage of connecting an output of the optical splitter 46 indirectly to the optical power meter 36, via the optical switch 46, is that such a scheme allows the optical power meter 36 to conveniently be used for other applications, such as direct measurement of the output power of the optical transceiver 10, by reconfiguring the optical switch 40. Alternatively, and as illustrated in Fig. 7, the second portion of the optical signal received by the optical splitter 46 may be connected to the receiver on transceiver card 10. While a pre-qualified transceiver 50 is illustrated in the present embodiment, it should be appreciated a standalone reference receiver 48 may be employed. The electrical output signal from the optical receiver 48 is coupled to a bit error rate tester 52. The reference receiver 48 may optionally be part of the BER tester 52. The optical signal employed may comprise a SONET OC-48 signal or any other desired optical signaling protocol and signaling rate.

Fig. 2 is a block diagram illustrating the logical layout of relevant functionality in an optical transceiver board 53 which corresponds to the board under test 10 in Fig. 1. The optical transceiver board 53 includes an electro-absorption (EA) modulated laser 73 which can be biased and/or tested by the disclosed system. The optical transceiver board 53 includes a

processor 54 which is coupled to a number of circuits on the optical transceiver board 53, for example by way of communications bus 81. The processor 54 is also coupled to the test controller 14 via a serial interface 56 and a serial communications link 57, which in the present embodiment is illustrated as an RS-232 serial interface shown as connection 20 in Fig. 1. Any other suitable communications interface, whether serial or parallel, may be used in combination with or as an alternative to the link 57. The test controller 14 of Fig. 1 thus has access to the various circuits coupled to the communication bus 81 via the processor 54. The communication bus 81 is coupled to a modulation depth control circuit 58, an electro-absorption bias offset control circuit 59, a back facet monitor 66 on the EA laser 73 via an analog to digital converter 65, a laser temperature monitor output on the EA laser 73 via an analog to digital circuit 67, a laser power current control circuit 69, and a thermo-electric cooling (TEC) control circuit 71. Note that in Fig. 2 A/D and D/A functionalities are shown without the conventional associated signal conditioning electronics for simplicity. The input 64 and output 80 are coupled to optical transmitter and receiver modules (WDM or otherwise) 89 and 90 respectively, and thus the input and output signals to the transceiver board under test are preferably optical. In this way, transceiver modules 89 and 90 may generate the appropriate electrical signals 64 and 80. In such an embodiment, the BER input and drive signals to module 10 on Fig. 1 are actually optical. For example, short reach standard SONET transceiver modules can be employed. Alternatively, the electrical input 64

may be provided to the Modulation Depth control circuit 58 and the electrical output signals provided as optical transceiver assembly 53 outputs.

The modulation depth control circuit 58 controls the amplitude of the modulation input signal 60 applied to the modulated laser 73,. The modulation signal 60 is AC coupled to the modulation input 79 of the EA laser 73 via a capacitor 61. Additionally, the output 62 of the EA Bias Offset Control Circuit 59 is coupled to the EA laser modulation input 79 via an inductor 63. The output 62 of the EA bias offset control circuit 59 determines the DC bias offset voltage applied to the EA laser 73 and is employed generally to set the center value of the modulation applied to the EA laser 73 as is discussed in greater detail below. The sum of the outputs from the Modulation depth control circuit and the EA bias offset control circuit thus comprises the input modulation signal 79 to the EA laser 73. Note that the simple bias-T consisting of the capacitor 61 and inductor 63 may be made up of other elements, as is known in the art. Furthermore, the modulation depth controller 58 and offset controller 59 can be combined into one device thus eliminating the need to externally couple the two signals.

A back facet monitor circuit (BFMC) 65 includes an analog to digital converter that receives the output of the back facet monitor 66 of the EA laser and converts the analog back facet monitor output signal to a digital signal. The back facet monitor 66 may be employed to monitor the output power of the EA laser 73 in place of the power meter 36. Alternatively, the optical transceiver 53 may include an on-board power meter that

may be employed for this purpose. The temperature monitor circuit (TMC) 67 includes an analog to digital converter that receives an analog signal indicative of the temperature of the EA laser 73 and converts the received analog signal to a digital signal. The temperature monitor is employed to determine the desired temperature of operation for the EA laser 73 at the central operating wavelength. The thermal electric cooling (TEC) control circuit 71 controls the TEC input 72 of the modulated laser 73 so as to control the temperature of the EA laser 73 and thereby maintain the transmission wavelength within parameters defined for the specific EA laser being employed. The laser power current control circuit 69 controls a laser bias current 70 applied to the EA laser 73 and is employed to establish the maximum operating power of the EA laser 73.

As described above, the EA laser 73 shown in Fig. 2 has a laser power current input 70 and an EA modulation input 79 which is voltage controlled. It should be appreciated that the inputs to the EA modulated laser may be either voltage or current controlled with appropriate modifications to the laser power control circuit 69 and the EA Bias Offset Control circuit 59, respectively.

It will also be recognized that while separate analog to digital converters 65 and 67 are shown in Fig. 2, a single analog to digital may be employed that is time multiplexed to sample the temperature output and back facet monitor 66 output of the EA laser 73.

The optical transceiver board 53 receives an optical input signal at an optical input 78 which is coupled to a photodetector 75. The photodetector 75 may, for example, be an avalanche photo-diode (APD) or a PIN photodiode, or

any other suitable photodetector. The output of the photodetector 75 is an electrical signal which is coupled to an amplifier 76. The amplifier 76, containing suitable signal conditioning such as automatic gain control (AGC) and filtering, passes the amplified received signal to a clock and data recovery circuit 77. The clock and data recovery circuit produces outputs 80 including clock and data signals 80a and 80b respectively from the amplified received signal. As described above these signals may drive another optical transceiver, such as a low cost 1310 nm customer side interface or another WDM interface used in a WDM regenerator application.

Fig. 3 is a graph showing relative optical output power 91 of the EA laser 73 as a function of electro-absorption modulator offset bias voltage 82. There are a variety of methods to arrive at optimal laser and EA signal settings. In one embodiment, the disclosed system operates to first bias the laser in the system to establish a predetermined peak optical output power. This can be set by monitoring the power of the laser section by monitoring the back facet monitor 66 (Fig. 2). The laser power current input 70 is adjusted until the peak optical power is verified on the back facet monitor 66. The back-facet monitor 66 gain in conjunction with the BFMC circuit 65 may be characterized using conventional methods, including, for example, using a manufacturer's data sheet value for mW/mA, where mW/mA is laser power in mW vs mA of back-facet photo-current. Alternatively, by setting the EA modulation voltage to zero and setting the EA bias voltage to zero, the desired laser output power can be read using power meter 36 with the appropriate configuration of the optical switch 40.

With the modulation set to minimum or off, the electro-absorption offset bias voltage is increased in the negative direction until it reaches a value $-(X + \Delta)$ 86 at which point the optical output power of the laser is a predetermined fraction of the peak output power 83, for example -12dB 85. The optical output power during this adjustment, for example, follows a curve such as curve 84 which may vary from device to device.

Because, for most common laser types, it is undesirable to apply a positive EA Offset bias to the EA laser 73, care is taken to bias the EA laser 73 such that when modulated, the EA offset bias never significantly crosses the zero axis. Otherwise, the EA section will become forward biased and its bandwidth and transmitter eye pattern and chirp may degrade. Accordingly, the EA laser bias offset is set at $-(X/2 + \Delta)$ in the absence of modulation. Thus, upon the application of a modulation 88 of size X , the EA signal 79 swings from in the negative direction between $-\Delta$ and $-(X+\Delta)$. Δ is selected based on the desired system application. In general, it is desirable to get as much output power (efficiency) from the laser. Accordingly, Δ should be close to zero. However, sometimes the chirp of the transceiver will be better if Δ is approximately -0.3V.

Figs. 4a-4b show steps performed in an illustrative embodiment to perform in-circuit biasing of the EA laser 73. The steps of Figs. 4a-4b may, for example, be performed in response to a computer program executing on the test controller 14 as shown in Fig. 1. At step 100 of Fig. 4a, the data input signal 64 to the modulated laser is turned off or the data input signal 64 is

disabled, and the modulation depth control signal is set to its minimum value, resulting in a minimum modulation signal 60. For example, the transmit data signal 64 is set to a steady state and the input to the depth control circuit 58 is set to generate the minimum amplitude modulation output signal 60.

At step 102, the laser power bias current 70 of Fig. 2 is set to a desired starting laser bias current value. Typically, the starting value is selected based upon a data sheet for the device to produce a laser output power which is less than the desired final laser output power. At step 104, the TEC input 72 to the modulated laser is adjusted until the fundamental wavelength of the laser is centered on the desired frequency. The frequency is measured via the use of the wavemeter 30 and the data indicative of the measured frequency is accessed by the test controller over the bus 22 as illustrated in Fig. 1. Optionally, the transceiver 10 by have an on-board or on-chip wavelength locker circuit (not shown). In that case, the signals from the wavelength locker can be recorded (as the desired values) and stored into a memory, such as the memory 55.

At step 106, the optical output power of the laser is measured via use of the power meter 36. It should be noted that at step 106, the optical switch 40 shown in Fig. 1 may or may not be configured to pass the output of the transceiver 10 to the input of the splitter 42. For example, the optical switch may be configured such that it redirects the light from transmitter 8 on transceiver board 10 directly to the optical power meter 36. The losses in the connectors and switch may be calibrated using conventional techniques so that upon measuring the

laser output power at meter 36 the measured power can be corrected to yield the actual output power of transceiver 10. Alternatively, another power meter can be coupled to splitter 42 by making it a 1x3 splitter instead of a 1x2 splitter. The data indicative of the measured power is accessed by the test controller over the bus 22 depicted in Fig. 1. At step 110, the laser power bias current is measured and compared with a predetermined maximum value. If the laser power bias current is greater than the predetermined maximum value, then step 110 is followed by step 112, in which the test is discontinued because the EA laser or some other component in the test system is defective. Otherwise, at step 114, the optical output power of the laser measured at step 106 is compared with a desired laser peak output power. If the measured optical output power of the laser is substantially equal to the desired laser peak output power, then step 114 is followed by step 118. Otherwise, step 114 is followed by step 116, in which the laser power bias current is increased (or decreased) by a predetermined increment by controlling a digital to analog converter associated with the laser current control circuit 69. Step 116 is followed by step 104. In this way, steps 104 through 114 are repeated until the desired peak output power is reached, for example corresponding to the peak output power 83 shown in Fig. 3. At step 118, the test controller 14 records the laser power current bias value that produced the desired peak output power for the EA laser 73. Step 118 is followed by step 120 as shown in Fig. 4b. The peak output power corresponds generally to the EA laser on-state output power. As discussed above, the laser output power can be measured by optical power

meter 36 or via the back facet monitor 66. If an optical power meter 36 is used for this purpose it can be used to calibrate the back facet monitor 66 to a desired value in an automatic power control loop in the BFMC circuit 65.

At step 120, the EA bias offset circuit 59, as shown in Fig. 2, is adjusted by iteratively controlling a digital to analog converter associated with that circuit and measuring the EA laser 73 output power until the optical output power of the EA laser 73 substantially equals a predetermined desired off-state power. For example, a desired off-state power may be approximately 12dB down from the peak output power of the laser recorded at step 118, or any other appropriate proportion of the measured peak output power. At step 122, the electro-absorption offset bias voltage providing the desired off-state power is recorded as the off-state electro-absorption offset bias voltage. Next, at step 124, the center of the modulation provided by the electro-absorption modulator in the modulated laser is established by setting the EA offset bias voltage to:

$$-(\text{electro absorption off-state bias}/2 + \Delta)$$

where Δ is a predetermined offset provided so that the laser does not operate with a positive EA offset bias, and minimal chirp, and this value is recorded as the operational EA offset bias voltage value. For example, a typical Δ value might be on the order of $-(.3 - 1.0)$ volt. For example, the center of the modulation is set by writing a control register in the electro-absorption bias offset control circuit 59 shown in Fig. 2. At step 126, the electro-absorption modulation input is enabled, such that input data to be transmitted 64 is applied to

the modulation depth control circuit 58 and the output of the modulation depth control circuit 58 is summed with the EA bias offset control circuit 59 output. At step 128, the electro-absorption modulation depth or, otherwise stated, the amplitude of the modulation applied to the EA laser modulation input 79, is adjusted to obtain either a predetermined output drive level of X or a predetermined desired extinction ratio, which is the ratio of the optical power representing a 1 bit and the optical power representing a 0 bit. For example, the modulation depth may be adjusted by writing into a control register within the modulation depth control circuit 58 a value which produces the desired amplitude of modulation at the output 60 to obtain the specified extinction ratio. The extinction ratio is measured by the communication analyzer 24 and the measurements are accessible by the test controller over the bus 22 as illustrated in Fig. 1. At step 130, the test controller stores in a memory within the optical transceiver 53 register values which are input to the respective digital to analog converters to obtain the desired peak output power recorded at step 118, the electro-absorption operational offset bias determined at step 124, and the electro-absorption modulation voltage associated with the modulation depth obtained in step 128. For example, these values may be written into a non-volatile memory such as the memory 55 shown in Fig. 2 for loading into registers with the respective bias control circuits, and/or into non-volatile registers within the respective control circuits 58, 59 and 69 so as to permit such values to be later used during operation of the optical

transceiver board when installed in an optical communications device.

Fig. 5 shows illustrative steps performed to perform bit error rate testing of an optical transmitter 8 (See Fig. 1) and an optical receiver 9 (See Fig. 7) within an optical transceiver 10. The steps of Fig. 5 may, for example, be performed under control of a test controller, such as the test controller 14 shown in Fig. 1. The steps of Fig. 5 may be employed to test the optical transmitter 8 of an optical transceiver 10 using the configuration shown in Fig. 1, or to test the optical receiver of a device using the configuration shown in Fig. 7, or to test a combination of both an optical transmitter and an optical receiver at the same time. For purposes of illustration, the steps of Fig. 5 are described with relation to the testing of an optical transmitter 8, as shown in the configuration of Fig. 1. In this example, the system under test is the optical transceiver board 10, and the optical communications device 50 is a pre-qualified transceiver that includes a reference receiver 48 and a reference transmitter 51 having known and acceptable reception and transmission characteristics respectively.

At step 140 of Fig. 5, an optical wavemeter, such as the wavemeter 30 shown in Fig. 1, which may for purposes of illustration be an HP 86120C or equivalent device, is used to measure an initial optical signal to noise ratio (OSNR). The initial optical signal to noise ratio is measured at step 140 with the first variable optical attenuator set by the test controller 14 to minimum attenuation and the second VOA set to a predetermined maximum necessary to prevent damage to the reference

receiver. At step 142, the attenuation provided by a first variable optical attenuator (VOA) is adjusted until the wavemeter indicates that a predetermined initial optical signal to noise ratio is present on the fiber being monitored. At step 144, a tuneable optical filter, such as the tuneable filter 32 (e.g. such as those available from JDS/Uniphase or SANTEC Corporations) shown in Fig. 1, is adjusted to the central wavelength of the laser under test. Next, at step 146, a second variable optical attenuator, such as the variable optical attenuator 34 shown in Fig. 1, is adjusted until a predetermined optical power level, appropriate for the optical receiver in the test configuration of Fig. 1, is obtained on the fiber. The power level is, for example, measured using the power meter 36 as shown in Fig. 1.

At step 148, a bit error rate tester, such as the bit error rate tester 52 shown in Fig. 1, determines a current bit error rate, based on a comparison of bits transmitted by the transmitter 8 within the optical transceiver 10 and bits received by the reference receiver 48 within the reference transceiver 50. The bit error rates measured at step 148 are recorded, along with the associated optical signal to noise ratio, for later use in step 152. At step 150, the bit error rate measured at step 148 is compared with a predetermined termination level, for example 10^{-10} bit errors per second. This value can be decreased (e.g. 10^{-12}) to allow better accuracy of the final projected BER at the expense of throughput time. If the measured bit error rate is less than the predetermined termination level, then step 150 is followed by step 152. Otherwise, step 150 is followed by step 154, in which the first variable optical

attenuator is adjusted by a predetermined step value to increase the optical signal to noise ratio on the fiber as measured by the wavemeter 30 or other suitable OSNR measuring device or technique. Step 154 is followed by step 146. In this way, steps 146 through 154 are repeated until a number of bit error rates have been recorded in response to variations in the OSNR and the predetermined termination level bit error rate is achieved.

While the termination condition checked at step 150 is shown for purposes of illustration as comparing a current measured bit error rate with a predetermined termination bit error rate of 10^{-10}, any suitable bit error rate may be employed. Alternatively, a predetermined termination optical signal to noise ratio may be compared with the current optical signal to noise ratio in order to terminate the loop of steps 146 through 154.

At step 152, the bit error rates measured at step 148, and their associated optical signal to noise ratios, are used to estimate an optical signal to noise ratio that will result in a predetermined bit error rate considerably less than the measured optical signal to noise ratios. For example, an optical signal to noise ratio may be projected at step 152 for a bit error rate of 10^{-15} bit errors per second. The estimation performed at step 152 may, for example, be performed using a least squares technique on a log(log(BER)) vs OSNR (dB) scale, or any other appropriate extrapolation technique.

At step 156, the projected optical signal to noise ratio determined at step 152 is compared to a specified maximum optical signal to noise ratio for the

predetermined bit error rate. If the projected optical signal to noise ratio is less than the specified maximum, then step 156 is followed by step 158, in which an indication is provided that the board under test has passed the bit error rate test. Otherwise, step 156 is followed by step 160, in which an indication is generated that the board under test has failed the bit error rate test.

Alternatively, at step 156, based upon the extrapolated bit error rate versus OSNR function, a higher OSNR could be specified than the measured OSNR values and a determination made regarding the projected bit error rate at the specified higher OSNR. If the projected bit error rate at the specified higher OSNR is below a predetermined maximum bit error rate, an indication is generated that the board has passed the test. Otherwise an indication is provided that the board under test has failed the bit error rate test.

Fig. 6 is a graph showing a measured bit error rate 182 of a device under test as a function of a controlled optical signal to noise ratio 184 and depicts the bit error rates discussed with respect to the flow diagram of Fig. 5. Fig. 6 illustrates how the disclosed system projects an estimated optical signal to noise ratio 186 for a predetermined, relatively low bit error rate 188, from a set of points 190 reflecting measured, relatively high bit error rates associated with generated optical to signal to noise ratios. As shown in Fig. 6, a line 192 is calculated using an extrapolation technique such as a least squares fit technique (on this log(log(BER)) vs OSNR (dB), based on the points 190. The intersection of the calculated line with the predetermined, relatively

low bit error rate 188 determines the projected optical signal to noise ratio 186 for that bit error rate. If the projected optical signal to noise ratio 186 is greater than a limit 194, then an indication is provided that the board under test has failed the bit error rate test. If, on the other hand, the projected optical signal to noise ratio 186 is less than the optical signal to noise ratio limit 194, then an indication is provided that the board has passed the test.

Note that an alternative to measuring the transmitter BER vs OSNR quality is to use a swept receiver threshold "Q" measurement technique. Using such a technique, it is not necessary to vary the OSNR as described above, but rather the OSNR is set at a desired operating point, such as 20 dBm in a 0.1 nm optical bandwidth. The received optical power is then set, for example to -20 dBm. Then the receiver threshold is swept out and the BER is plotted as a function of this threshold. The "Q" is then arrived at by fitting the measured data, as is conventional. If the measured "Q" is greater than the desired "Q" then the device passes.

While the above discussion focuses on measuring the quality of the transmitter into a reference receiver, the disclosed system can further be used to measure receiver performance for a reference transmitter. A corresponding graph similar to that shown in Figure 6 can be generated to screen receivers. In addition, if the receiver has a built in adjustable decision threshold then a corresponding swept "Q" measurement can also be made on a received signal with the appropriate received signal power and OSNR, consistent with the disclosed system.

Fig. 7 shows the illustrative testing environment of Fig. 1 configured to perform bit error rate testing on an optical receiver 9 within the optical transceiver board 10. As shown in Fig. 7, the devices and connections are as depicted in Fig. 1, with the exception being that the output of a reference transmitter 51 in the reference system 50 is passed through the optical switch 40 to the input of the signal splitter 42, and one of the outputs of the signal splitter 46 is passed through the optical switch 40 to the input of the optical receiver 9 of the board under test. Additionally, as illustrated in Fig. 7, the bit error rate tester 52 drives the reference transmitter 51 and receives the received data stream from the optical receiver 9 under test. In the configuration of Fig. 7, the bit error rate tester 52 determines a current bit error rate by comparing bits transmitted from the reference system 51 and received by the receiver function 9 of the board under test.

As described above, the inputs to the receiver and/or the transmitter module 10 can be optical and the reference receiver and/or transmitter may be eliminated employing instead, the receiver and/or transmitter integrated into transceiver 10.

While the functions described herein are illustrated as being controlled by the test controller 14 it should be appreciated that such functions may be shared between the test controller 14 and the processor 54. In that event, the processor 54 may have direct or indirect access to some or all of the devices coupled to the communications bus 22.

Those skilled in the art should readily appreciate that the programs defining the functions of the test

controller can be delivered to a computer in many forms; including, but not limited to: (a) information permanently stored on non-writable storage media (e.g. read only memory devices within a computer such as ROM, PROM, EEPROM or CD-ROM disks readable by a computer I/O attachment); (b) information alterably stored on writable storage media (e.g. floppy disks and hard drives); or (c) information conveyed to a computer through communication media for example using baseband signaling or broadband signaling techniques, including carrier wave signaling techniques, such as over computer or telephone networks via a modem. In addition, while the test controller functions may be embodied in computer software, the test controller functions may alternatively be embodied in part or in whole using hardware components such as Application Specific Integrated Circuits or other hardware, or some combination of hardware components and software.

While the invention is described through the above exemplary embodiments, it will be understood by those of ordinary skill in the art that modification to and variation of the illustrated embodiments may be made without departing from the inventive concepts herein disclosed. Accordingly, the invention should not be viewed as limited except by the scope and spirit of the appended claims. In particular, while the body of this disclosure has discussed EA modulated lasers, this approach also applies to directly modulated or other externally modulated laser devices.

CLAIMS

What is claimed is:

1. A method for in-circuit testing of a modulated laser on an optical transmitter assembly, said modulated laser having at least one bias control input, said at least one bias control input coupled to at least one bias control circuit on said optical transmitter assembly, said bias control circuit operative to control an output light beam produced by said modulated laser responsive to at least one control value, comprising:

initiating, in a processor communicably coupled to said at least one control value, a bias adjustment sequence; and

iteratively, in response to said initiation of said bias adjustment sequence, adjusting said at least one control value and measuring at least one characteristic of said output light beam until said at least one characteristic substantially equals a predetermined value.

2. The method of claim 1, wherein said modulated laser comprises an electro-absorption modulated laser.

3. The method of claim 2, wherein said measuring said at least one characteristic comprises measuring an output power of said modulated laser, and wherein said adjusting comprises adjusting said at least one control value in order to adjust said output power of said modulated laser.

4. The method of claim 1, wherein said processor is embodied within a test controller external to said optical transmitter assembly, and wherein said test controller and said optical transmitter assembly each include a communications interface and said test controller and said optical transmitter assembly are communicably coupled via said communication interfaces.

5. The method of claim 1, wherein said transmitter assembly includes said processor.

6. The method of claim 1, wherein said measuring step further comprises the step of measuring said at least one characteristic of said output light beam using a measurement device including an input receiving at least a portion of said light beam.

7. The method of claim 6, wherein said measurement device is an optical power measuring device.

8. The method of claim 1, wherein said measuring device is a communication analyzer and said characteristic of said light beam is an extinction ratio.

9. A system for in-circuit testing of a modulated laser on a transmitter assembly, wherein said modulated laser has at least one bias control input, said at least one bias control input is coupled to at least one bias control circuit, and said bias control circuit operative to control an output light beam produced by said modulated laser responsive to at least one control value, comprising:

a processor for controlling said at least one control value, and operative to perform a bias adjustment sequence, said bias adjustment sequence including adjusting said at least one control value and measuring at least one characteristic of said output light beam until said at least one characteristic substantially equals a predetermined value.

10. The system of claim 9, wherein said modulated laser comprises an electro-absorption modulated laser.

11. The system of claim 10, wherein said processor is operative to access said at least one characteristic by accessing a measurement of an output power of said modulated laser, and wherein said processor is operative to control the adjustment of said at least one control value in order to adjust said output power of said modulated laser.

12. The system of claim 9, further comprising a test controller external to said transmitter assembly, wherein said test controller includes said processor, and wherein said test controller is communicably coupled to said transmitter assembly through a communication interface.

13. The system of claim 9, wherein said transmitter assembly includes said processor.

14. The system of claim 13, wherein said processor is operative to execute a control program to perform said bias adjustment sequence.

15. The system of claim 9, further comprising a measurement device optically coupled to at least a portion of said output light beam and communicably coupled to said processor, for performing said measurement of said at least one characteristic of said output light beam.

16. The system of claim 15, wherein said measurement device is an optical power measuring device.

17. The system of claim 16, wherein said measurement device is a communications analyzer and said measured characteristic is an extinction ratio.

18. A method for in-circuit testing of an optical transceiver assembly including at least one modulated laser, said modulated laser having at least one bias control input, said optical transceiver assembly further including at least one bias control circuit coupled to said at least one bias control input and responsive to at least one control value, said bias control circuit operable to control an output light beam produced by said modulated laser, said optical transceiver assembly having a communication interface, said method comprising:

communicably coupling a test controller to said optical transceiver via said communication interface;

transferring information from said test controller to said optical transceiver assembly to control said at least one control value;

measuring at least one characteristic of said light beam produced by said modulated laser following the

application of said at least one control value to said at least one bias control circuit; and

iteratively performing said transferring and measuring steps until said at least one characteristic substantially equals a predetermined value.

19. The method of claim 18, wherein said modulated laser comprises an electro-absorption modulated laser.

20. The method of claim 19, wherein said measuring comprises measuring an output power of said modulated laser, and wherein said adjusting comprises adjusting said at least one control value in order to adjust said output power of said modulated laser.

21. A system for in-circuit testing of an optical transceiver assembly including at least one modulated laser having at least one control input, said optical transceiver assembly further including at least one bias control circuit coupled to said at least one control input and responsive to at least one control value to control an output light beam produced by said modulated laser, said optical transceiver assembly having a communication interface, comprising:

a test controller communicably coupled to said optical transceiver via said communication interface, said test controller operable to transfer information to said optical transceiver to control said at least one control value;

a measurement device for measuring at least one characteristic of said light beam produced by said modulated laser following the application of said at

least one control value to said at least one bias control circuit; and

wherein said test controller is further operative to iteratively perform said transferring and measuring steps until said at least one characteristic substantially equals a predetermined value.

22. The system of claim 21, wherein said modulated laser comprises an electro-absorption modulated laser.

23. The system of claim 22, wherein said processor is operative to measure said at least one characteristic by measuring an output power of said modulated laser, and said processor is operative to adjust said at least one control value in order to adjust said output power of said modulated laser.

24. A test system for testing an optical transceiver, comprising:

an optical transceiver including a modulated laser having at least one control input, said modulated laser operative to produce an optical output signal responsive at least in part to at least one input signal applied to said at least one control input, said optical transceiver further including bias control circuitry coupled to said at least one control input and operative to control characteristics of said optical output signal in response to at least one supplied bias value;

test monitoring apparatus for monitoring said optical output signal and generating optical output signal characteristic data;

a test controller communicatively coupled to said optical transceiver unit and said test monitoring apparatus, and operative to execute a test program, said test program operative to vary said at least one supplied bias value and to access said optical output signal characteristic data; and

said test controller test program further operative to vary said at least one supplied bias value until said optical output signal characteristic data substantially matches predetermined output optical signal characteristic data, and to cause at least one operational bias value to be stored on said optical transceiver for later use by said optical transceiver as said at least one supplied bias value.

25. The system of claim 24, wherein said modulated laser comprises an electro-absorption modulated laser.

26. The system of claim 25, wherein said processor is operative to measure said at least one characteristic by measuring an output power of said modulated laser, and said processor is operative to adjust said at least one control value in order to adjust said output power of said modulated laser.

27. The test system of claim 24 wherein said at least one control input includes a laser power control input.

28. The test system of claim 24, wherein said at least one control input includes a laser modulation control input.

29. The test system of claim 25 wherein said bias control circuitry includes:

a laser power control circuit coupled to a first one of said at least one input and operative to control a peak laser output power in response to a laser power bias value of said at least one supplied bias value,

a dc bias circuit coupled to a second one of said at least one input and operative to control a laser output power in the absence of modulation in response to a dc bias value of said at least one supplied bias value, and

a modulation depth control circuit coupled to said second one of said at least one input and operative to control an amplitude of a modulated signal applied to said second one of said at least one inputs in response to a modulation depth bias value of said at least one supplied bias value.

30. The test system of claim 29 wherein said test program is operative:

to adjust said laser power bias value until said laser output power is substantially equal to a predetermined peak laser output power;

to record said adjusted laser power bias value as a laser power bias operating value;

to adjust said dc bias value to until said laser output power is a predetermined fraction of said predetermined peak laser output power;

to record a dc bias operating value which is one-half of said adjusted dc bias value plus a predetermined offset and to apply said dc bias operating value to said dc bias circuit;

to adjust said modulation depth bias value to obtain a predetermined extinction ratio;

to record said adjusted modulation depth bias value employed to obtain said predetermined extinction value as a modulation depth bias operational value,

wherein said laser power bias operational value, said dc bias operational value and said modulation depth bias operational value comprise said at least one operational bias value.

31. A system for testing an optical transmitter, said optical transmitter having an input, said optical transmitter for generating an optically modulated data signal, said system comprising:

an adjustable optical signal to noise ratio generator coupled to said optically modulated data signal;

an optical receiver coupled to an output of said adjustable optical signal to noise ratio generator and having an output;

a bit error rate tester for measuring bit error rates, said bit error rate tester operable to monitor said input of said optical transmitter, said bit error rate tester further operable to monitor said output of said optical receiver; and

a test controller communicably coupled to said bit error rate tester and said optical signal to noise generator, said test controller operable to cause said optical signal to noise generator to generate a plurality of generated signal to noise ratios, said test controller further operable to access a plurality of bit error rates measured by said bit error rate tester and corresponding

to respective ones of said generated signal to noise ratios, said test controller further operable to generate a projected optical signal to noise ratio corresponding to a lower bit error rate than said measured bit error rates, said projected optical signal to noise ratio based upon the measured bit error rates at the respective generated optical signal to noise ratios, and for determining that said transmitter is acceptable if said projected optical signal to noise ratio at said lower bit error rate is at least as small as a predetermined optical signal to noise ratio.

32. The system of claim 31, wherein said adjustable optical signal to noise ratio generator includes a variable optical attenuator.

33. The system of claim 31, wherein said adjustable optical signal to noise generator further includes an erbium doped fiber amplifier.

34. A system for testing an optical receiver, said optical receiver for receiving an optically modulated data signal, said system comprising:

an optical transmitter for generating said optically modulated data signal;

an adjustable optical signal to noise ratio generator having an input coupled to said optically modulated data signal;

a bit error rate tester for measuring bit error rates, said bit error rate tester operable to monitor a signal associated with said transmitter and representative of said optically modulated data signal,

said bit error rate tester further operable to monitor said output of said optical receiver; and

a test controller communicably coupled to said bit error rate tester and said optical signal to noise generator, said test controller operable to cause said optical signal to noise generator to generate a plurality of generated signal to noise ratios, said test controller further operable to access a plurality of bit error rates measured by said bit error rate tester and corresponding to respective ones of said generated signal to noise ratios, said test controller further operable to generate a projected optical signal to noise ratio corresponding to a lower bit error rate than said measured bit error rates, said projected optical signal to noise ratio based upon the measured bit error rates at the respective generated optical signal to noise ratios, and for determining that said receiver is acceptable if said projected optical signal to noise ratio at said lower bit error rate is at least as small as a predetermined optical signal to noise ratio.

35. The system of claim 34, wherein said adjustable optical signal to noise ratio generator includes a variable optical attenuator.

36. The system of claim 34, wherein said adjustable optical signal to noise generator further includes an erbium doped fiber amplifier.

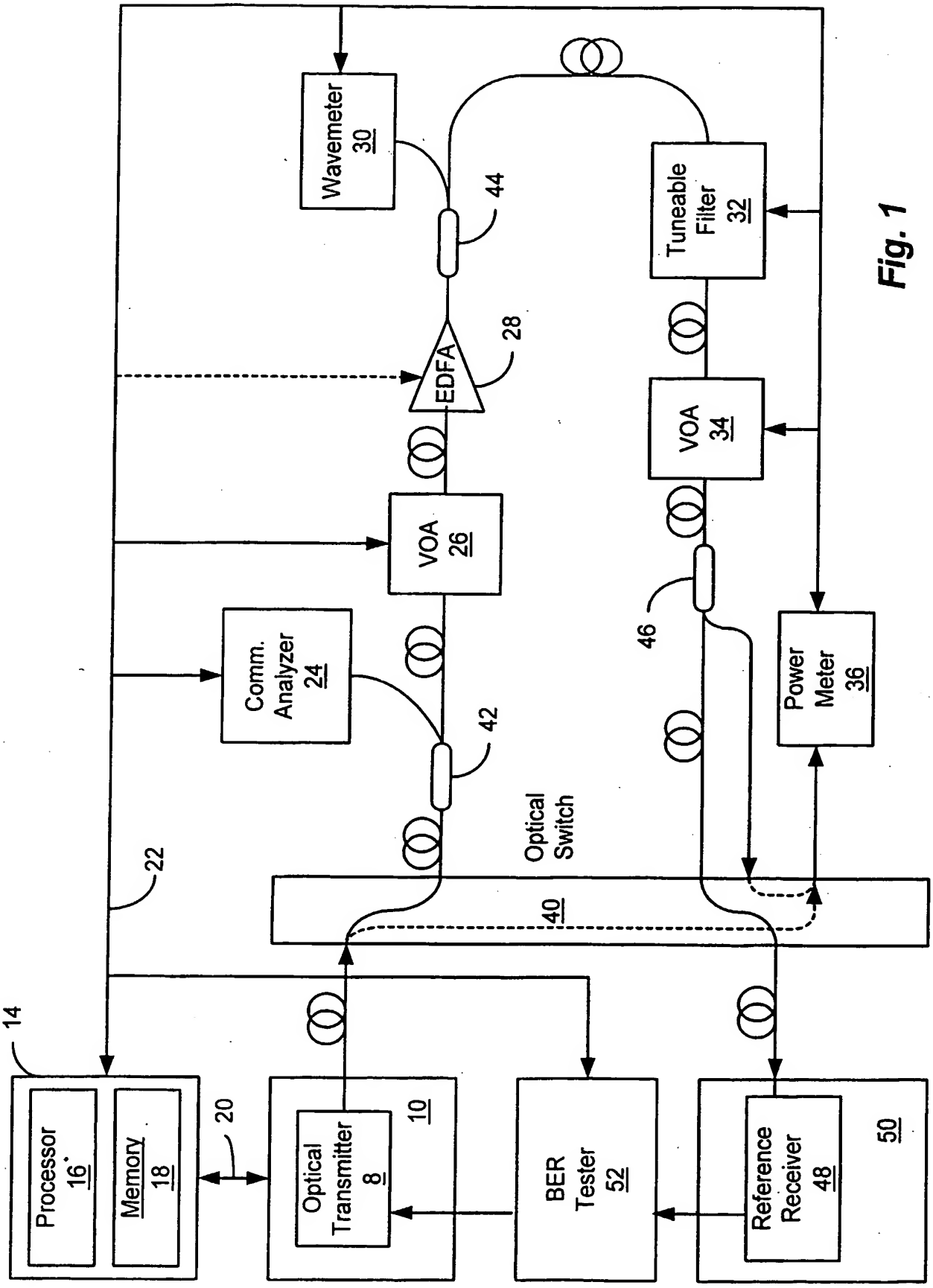
Wavemeter 30
44
Tuneable Filter 32
28
EDFA
VOA 34
VOA 26
46
Comm. Analyzer 24
Power Meter 36
42
Optical Switch
22
40
14
Processor 16
Memory 18
20
Optical Transmitter 8
10
BER Tester 52
Reference Receiver 48
50

Fig. 1

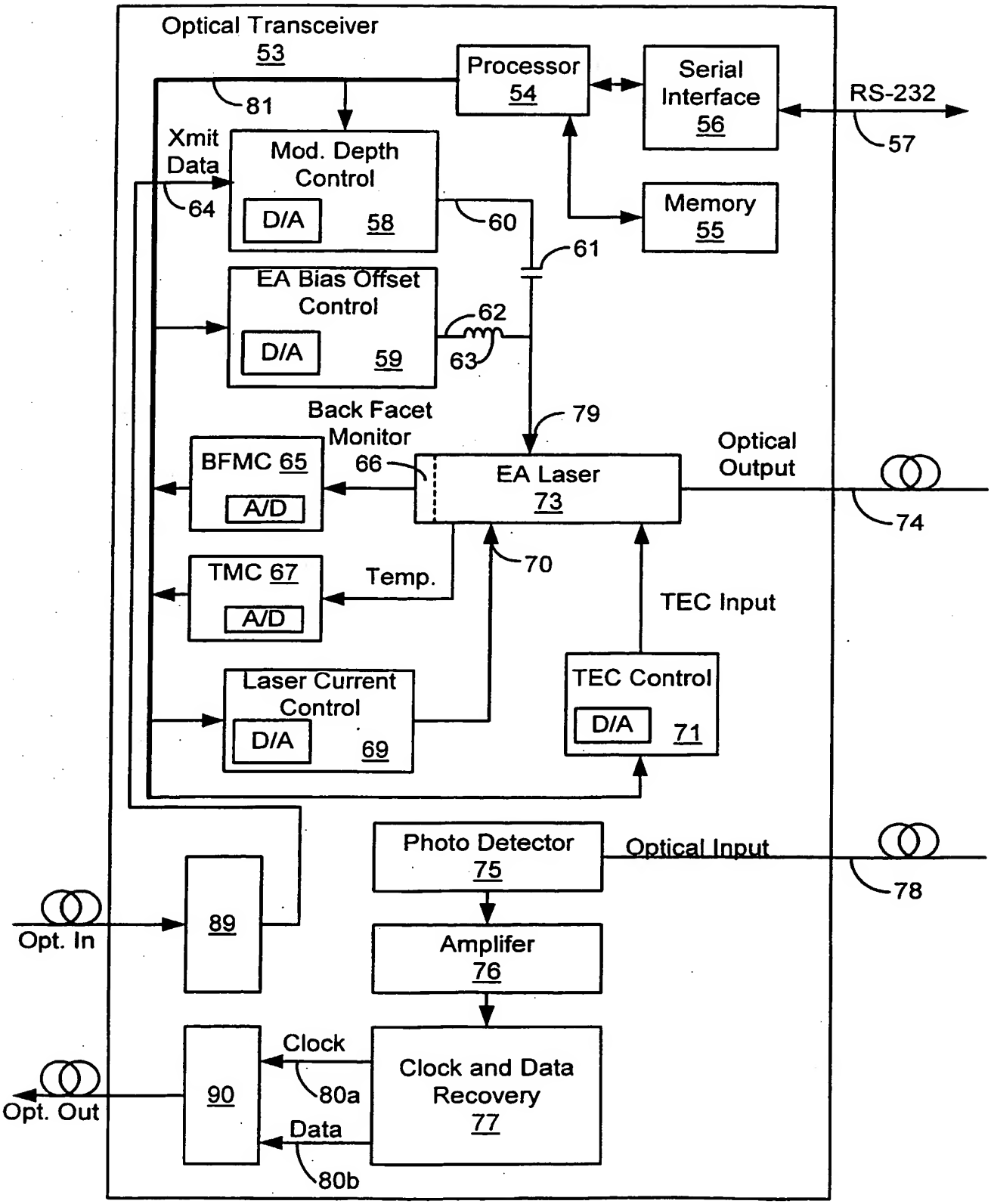
Optical Transceiver
53
Processor
54
Serial
Interface
56
RS-232
57
81
Xmit
Data
64
Mod. Depth
Control
D/A
58
60
Memory
55
61
EA Bias Offset
Control
D/A
59
62
63
Back Facet
Monitor
66
79
BFMC 65
A/D
EA Laser
73
Optical
Output
74
TMC 67
A/D
Temp.
70
TEC Input
Laser Current
Control
D/A
69
TEC Control
D/A
71
Photo Detector
75
Optical Input
78
89
Opt. In
Amplifer
76
90
Opt. Out
Clock
80a
Data
80b
Clock and Data
Recovery
77

Fig. 2

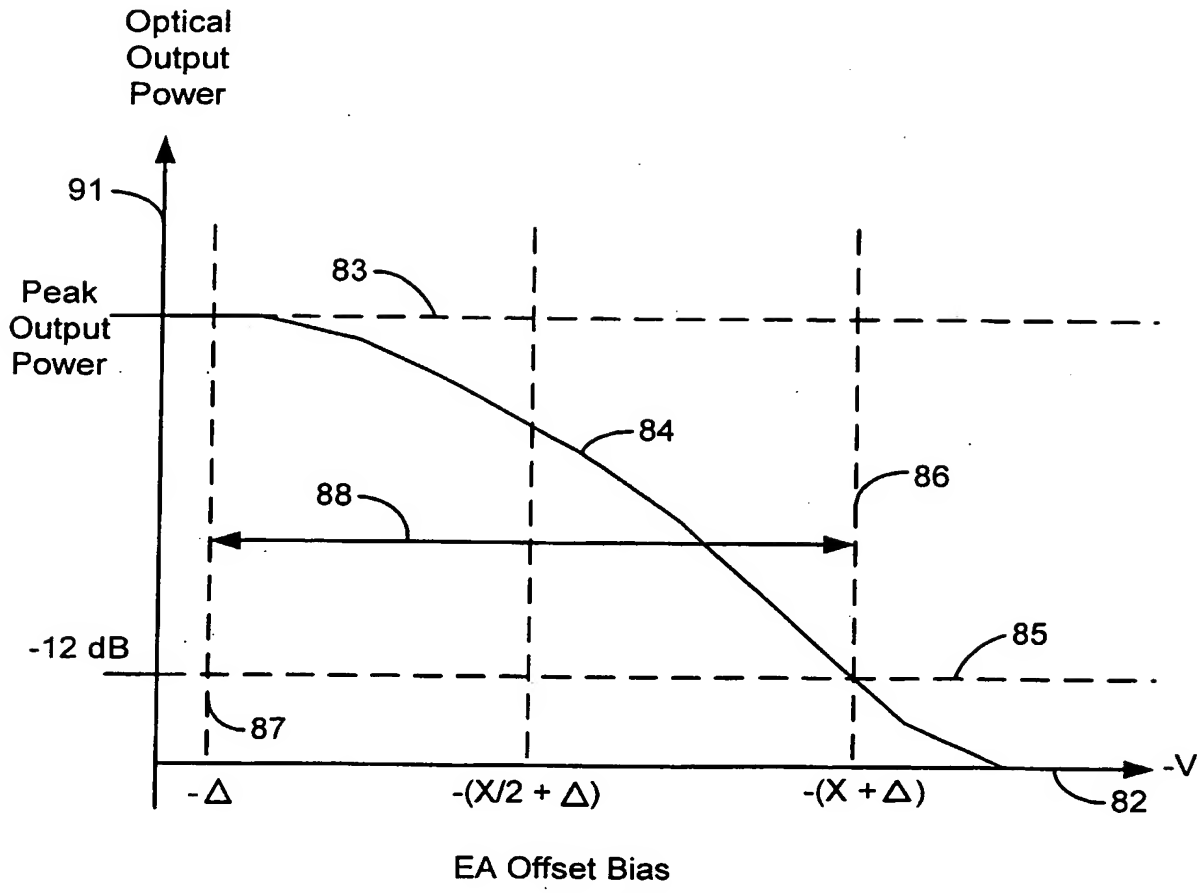
Optical
Output
Power
91
83
Peak
Output
Power
84
86
88
-12 dB
85
87
-V
-Δ
-(X/2 + Δ)
-(X + Δ)
82
EA Offset Bias

Fig. 3

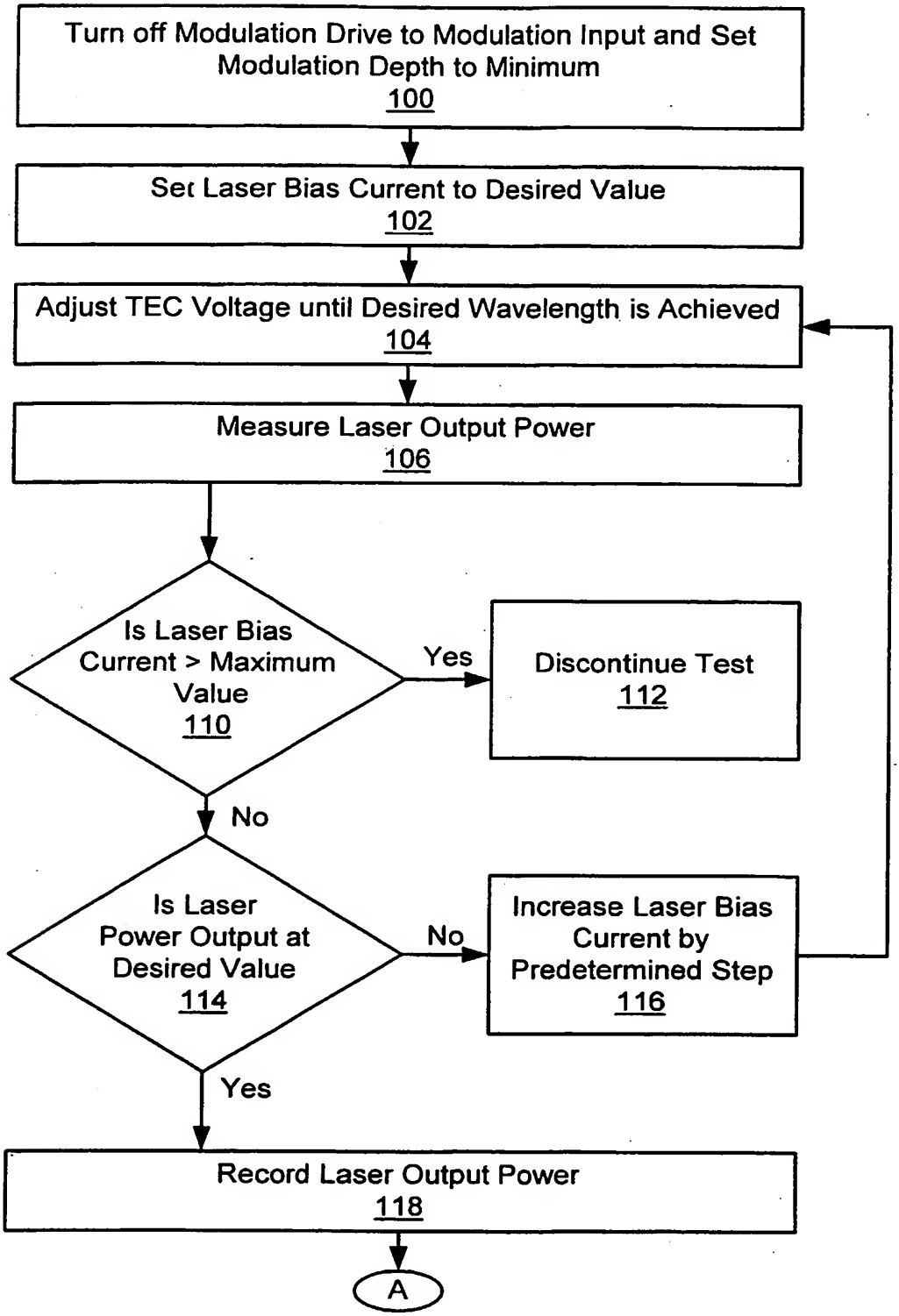
Turn off Modulation Drive to Modulation Input and Set Modulation Depth to Minimum
100
Set Laser Bias Current to Desired Value
102
Adjust TEC Voltage until Desired Wavelength is Achieved
104
Measure Laser Output Power
106
Is Laser Bias Current > Maximum Value
110
Yes
Discontinue Test
112
No
Is Laser Power Output at Desired Value
114
No
Increase Laser Bias Current by Predetermined Step
116
Yes
Record Laser Output Power
118
A

Fig. 4a

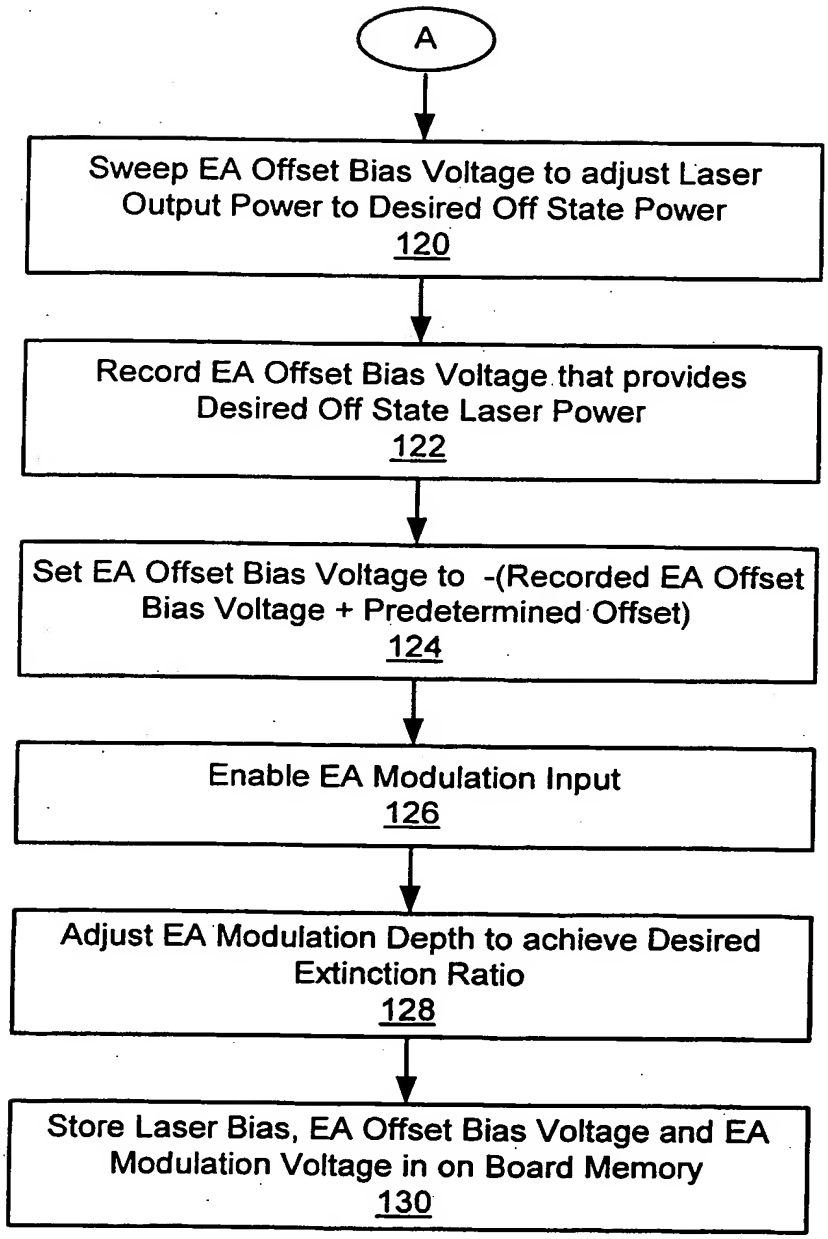
A
Sweep EA Offset Bias Voltage to adjust Laser Output Power to Desired Off State Power
120
Record EA Offset Bias Voltage that provides Desired Off State Laser Power
122
Set EA Offset Bias Voltage to -(Recorded EA Offset Bias Voltage + Predetermined Offset)
124
Enable EA Modulation Input
126
Adjust EA Modulation Depth to achieve Desired Extinction Ratio
128
Store Laser Bias, EA Offset Bias Voltage and EA Modulation Voltage in on Board Memory
130

Fig. 4b

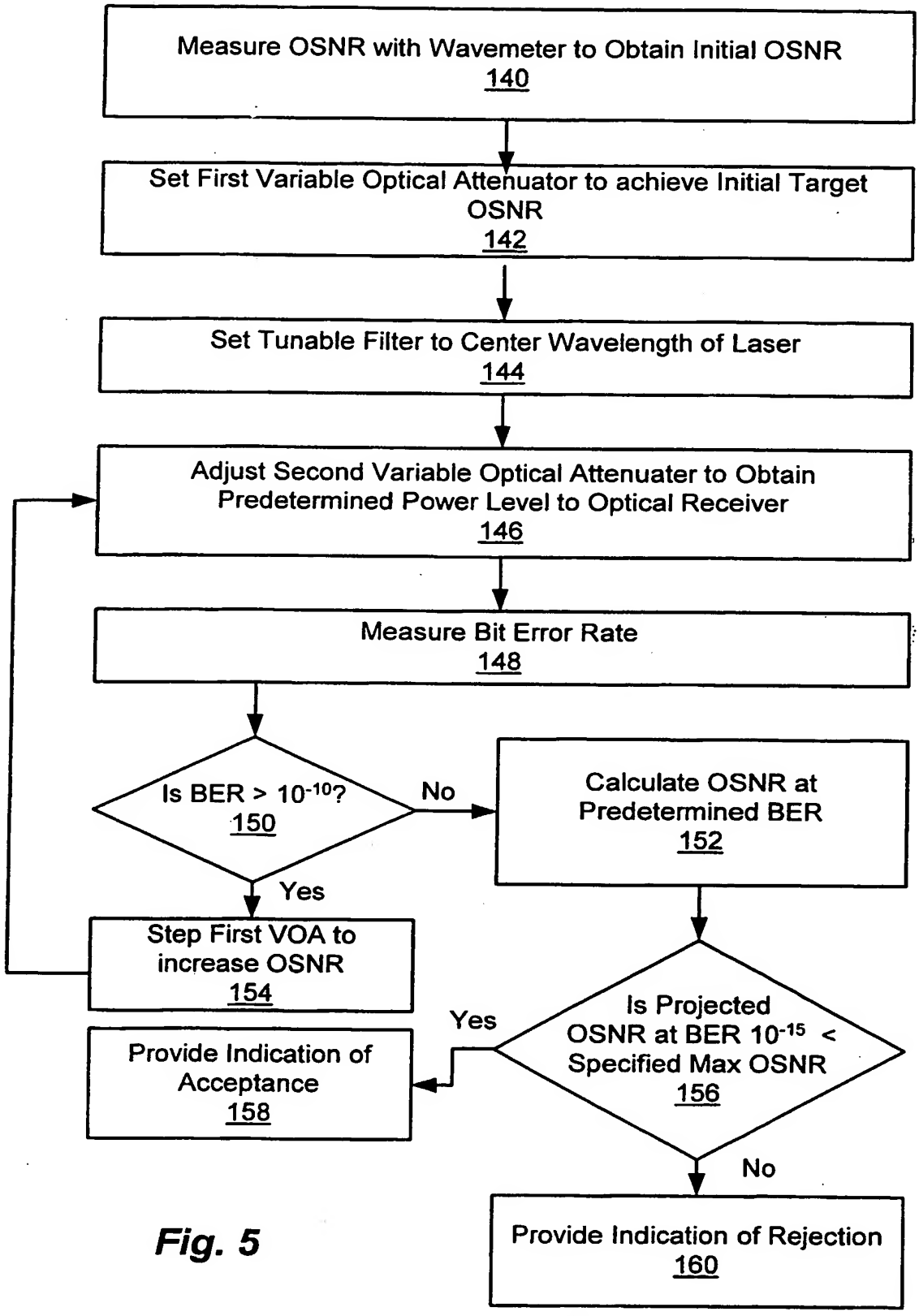
Measure OSNR with Wavemeter to Obtain Initial OSNR
140
Set First Variable Optical Attenuator to achieve Initial Target OSNR
142
Set Tunable Filter to Center Wavelength of Laser
144
Adjust Second Variable Optical Attenuater to Obtain Predetermined Power Level to Optical Receiver
146
Measure Bit Error Rate
148
Is BER > 10^{-10}?
150
No
Calculate OSNR at Predetermined BER
152
Yes
Step First VOA to increase OSNR
154
Is Projected OSNR at BER 10^{-15} < Specified Max OSNR
156
Yes
Provide Indication of Acceptance
158
No
Provide Indication of Rejection
160

Fig. 5

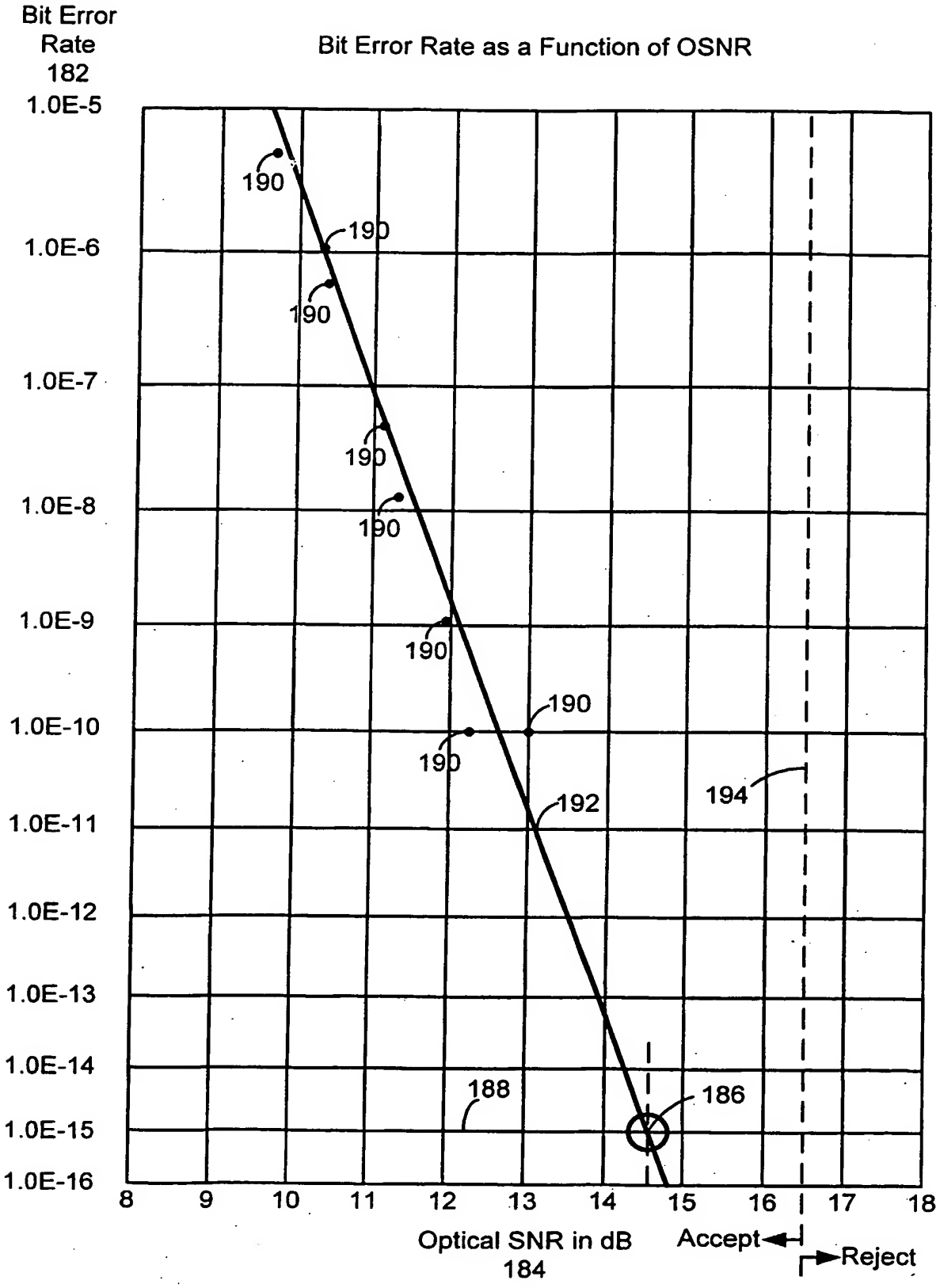
Bit Error Rate 182
Bit Error Rate as a Function of OSNR
1.0E-5
1.0E-6
1.0E-7
1.0E-8
1.0E-9
1.0E-10
1.0E-11
1.0E-12
1.0E-13
1.0E-14
1.0E-15
1.0E-16
190
192
194
188
186
8
9
10
11
12
13
14
15
16
17
18
Optical SNR in dB 184
Accept
Reject

Fig. 6

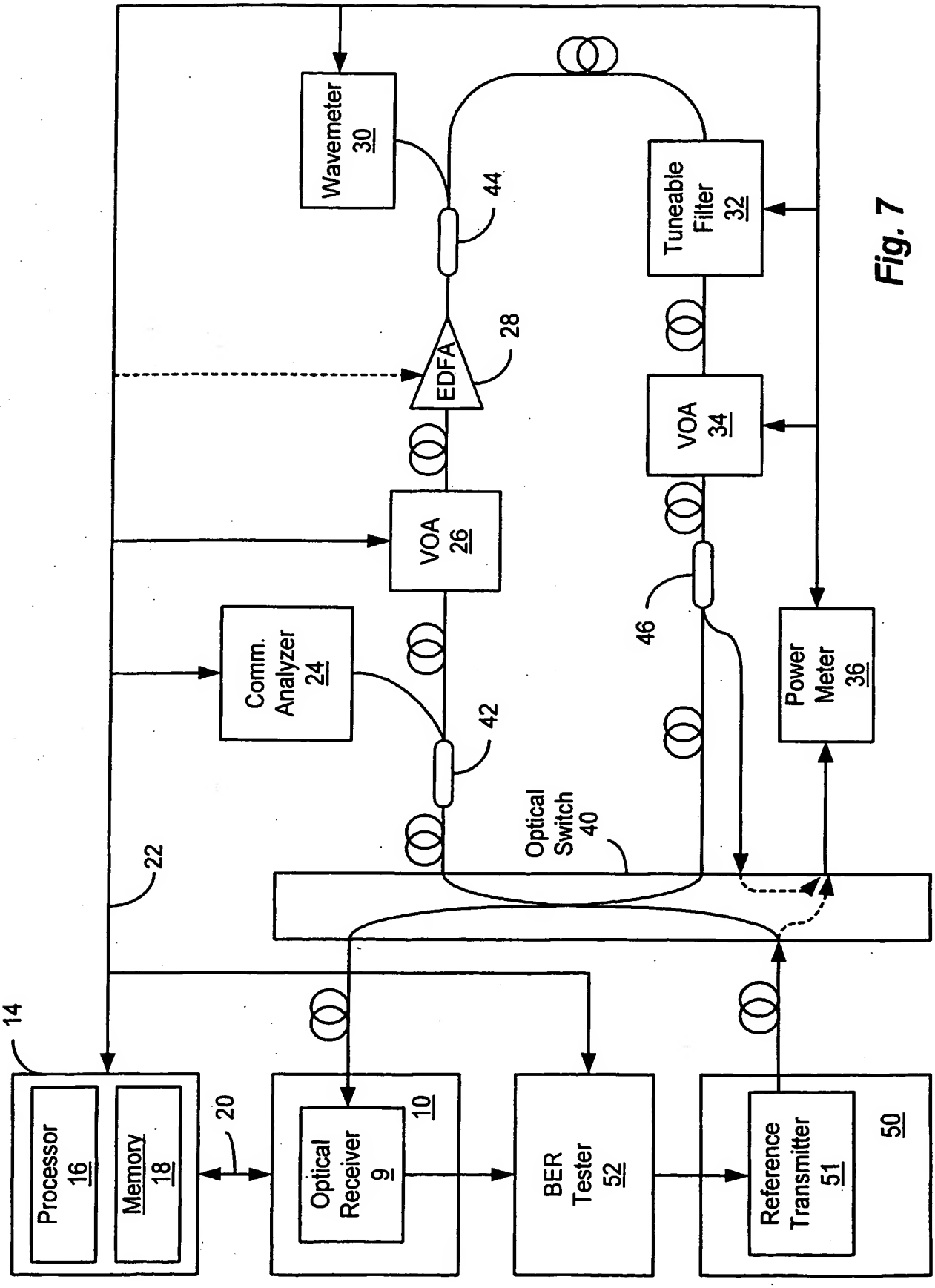
Wavemeter 30
44
Tuneable Filter 32
EDFA
28
VOA 34
VOA 26
Comm. Analyzer 24
46
Power Meter 36
42
Optical Switch 40
22
14
Processor 16
Memory 18
20
Optical Receiver 9
10
BER Tester 52
Reference Transmitter 51
50

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/35126

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H01S 3/13
US CL : 372/31

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 372/31

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,709,416 A (Patterson) 24 November 1987 (24.11.1987) Entire Doc.	1-36
A	US 4,537,502 A (Miller et al.) 27 August 1985 (27.08.1985) Entire Doc.	1-36
A	US 5,440,113 A (Morin et al.) 08 August 1995 (08.08.1995) Entire Doc.	1-36
A	US 5,402,433 A (Stiscia) 28 March 1995 (28.03.1995) Entire Doc.	1-36
A	US 4,718,118 A (Viola) 05 January 1988 (05.01.1988) Entire Doc.	1-36

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Date of the actual completion of the international search
03 March 2001 (03.03.2001)

Date of mailing of the international search report
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